Supporting Online Material for

How the Brain Translates Money into Force: A Neuroimaging Study of Subliminal Motivation

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Published 12 April 2007 on Science Express
DOI: 10.1126/science.1140459

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Material and methods

Subjects
The study was approved by the National Hospital for Neurology and Neurosurgery and the Institute of Neurology joint Ethics Committee. Subjects were recruited via Gumtree website and screened for exclusion criteria: left handedness, age below 18 or above 39, regular taking of drug or medication, history of psychiatric or neurological illnesses and contra-indications to MRI scanning (pregnancy, claustrophobia, metallic implants). All included subjects gave informed consent prior to taking part. A total of 18 subjects were scanned: 9 males (mean age 24.3 ± 5.4 years) and 9 females (mean age 25.9 ± 3.7 years).

Behavioral task and analysis
Subjects had first to read the instructions (see below) about the different tasks, which were later explained again step by step. Before scanning, subjects were familiarised with the masks and stimuli in a practice task. They were shown the basic sequence of computer screenshots (Fig. 1) used in all tasks designed for this study: cross / mask / stimulus / mask. The stimulus could be a penny (1p) or a pound (£1) coin. Subjects were asked to report whether or not they saw the coin, by pressing the left or right key. Different durations were used, all multiples of 17 ms, due to the refreshment rate of the computer screen (60 Hz). In the first trials the stimulus was displayed during 100 ms, and then its duration was decreased by 17 ms, following a stair-case procedure, until the subjects consistently (in 3 consecutive trials) reported not being able to see anything except the mask. With this method we found that 50 ms was sufficiently short to ensure all subjects could not perceive the stimuli.

Subsequently subjects were brought inside the scanner. They were invited to find an optimal body position, lying down with a power grip in the right hand, the arm folded up over the belly. The hand grip was made of two moulded plastic cylinders compressing an air tube. The tube led to the control room, where it was connected to a transducer able to convert air pressure into voltage. Thus compression of the two cylinders by an isometric handgrip resulted in the generation of a differential voltage signal, linearly proportional to the force exerted. The signal was fed into the stimuli presentation PC via a signal conditioner. Stimuli presentation was programmed with Cogent.
2000 (Wellcome Department of Imaging Neuroscience, London, UK). The visual stimuli were displayed behind the scanner on a projector screen, which subjects could see via mirrors positioned over their eyes. The dynamic changes of recorded signal were used to provide subjects with a real time visual feedback about the force being exerted on the grip, as a fluid level moving up and down within a thermometer (see Fig. 1).

We calibrated the baseline (“just do nothing”) and measured the maximal force (“squeeze the grip as hard as you can”). The thermometer was displayed on the screen, to let the subject practice moving up and down the fluid level. The scale was adjusted so that each subject would reach half of the total height of the thermometer when producing his/her maximal force. This was implemented to avoid ceiling effects in case the maximal force had been underestimated. In parallel to the force, we also continuously monitored galvanic skin conductance levels, from electrodes placed on the middle and index fingers of the left hand. However, due to technical problems, we could only record skin conductance data in 12 subjects out of 18.

Subjects then performed the incentive force task, divided into 3 sessions of 13 minutes. Each session contained 15 repetitions of 6 trial types, for a total of 90 trials. The 6 trial types correspond to 6 different stimulations, according to a 2*3 factorial design: 2 monetary stakes (1p and £1) and 3 different durations (17, 50 and 100 ms). In every trial the subject had to fixate the central cross and pay attention to the subsequent flickering image, composed of 3 successive screens: mask / stimulus / mask. When the thermometer appeared on the screen, subjects had to squeeze the power grip. They were told that the height they reached within the thermometer determined the fraction of the monetary stake they would keep. At the end of every trial a cumulative total was displayed, indicating the amount of money a subject had won so far. Subjects believed they were playing for real money, but at the end their payoff was rounded up to a fixed amount (£30). Before leaving they were debriefed about their feelings and intentions in the different situations (seeing £1, seeing 1p, seeing nothing).

After the functional scan, while performing the incentive force task, subjects had a structural scan, while performing a perception task. This task was designed to apply two criterions for subliminal perception: percentage of subjective seeing and percentage of correct guessing. Subjects observed the same first 4 screens (cross / mask / stimulus / mask). Then they were asked to figure out which coin was displayed, and to have a guess if they could not see anything. Thus they were forced to choose one of the 4 responses written on the screen: seen £1 / seen 1p / guess £1 / guess 1p. The response was chosen by pressing the corresponding button on the keypad. Stimuli and durations
were the same as in the incentive force task, but there was no pressure on the response time. Each of the 6 trial types was repeated 30 times, for a total of 180 trials, lasting about 10 minutes on average.

For the incentive force task, two parameters were considered: skin conductance and hand grip force. Skin conductance was down-sampled at 100Hz and mean filtered. The response to stimuli was taken as the difference between the maximum reached within 2-8 s interval and the mean over 0-2 s interval. Hand grip force was down-sampled at 50Hz and we extracted both the maximum reached and the area under the curve over 0-4s post-stimulus interval. The two parameters were expressed in percentage of the highest measure and then compared between monetary stakes using one-tailed paired t-tests. Mean group results are also illustrated either as a time course for the different trial conditions (Fig. 3) or as peaks reached trial after trial throughout the 3 task sessions (Fig. S1).

For the perception task, three parameters were considered: percentage of correct responses (£1 or 1p), percentage of seen responses (as opposed to guess responses) and response times (whatever the response). These parameters were compared between conditions using one-tailed paired t-tests (see illustration in Fig. 3). Percentage of correct responses was used to define subliminal situations in the sense that subjects were guessing at chance level. Using chi-2 test at individual level, guessing was found not to be different from chance level (50%) in 24 situations: at 17 ms for all 18 subjects and at 50 ms for 6 subjects. Using paired t-test at group level, guessing was also found not to be different from chance, with an average of 51 ± 4 %. We also checked that the discriminability index (d’) was not different from 0 in these situations, with an average of 0.19 ± 0.54. Percentage of seen responses was used to define subliminal situations in the sense that subjects had the subjective feeling to guess and not to see. These situations (n=36) correspond to the 17 and 50 ms in all subjects, with an average subjective seeing of 5 ± 16 %. The partitions operated by the two criterions for subliminal perception are illustrated in Fig. S2.

Images acquisition and analysis
T2*-weighted echo planar images (EPI) were acquired with blood oxygen dependant level (BOLD) contrast on a 3.0 Tesla magnetic resonance scanner. We employed a tilted plane acquisition sequence designed to optimize functional sensitivity in the orbitofrontal cortex and medial temporal lobes. To cover the whole brain with a short TR (1.95s), we used the following parameters: 30 slices; 2mm slice thickness; 2mm inter-slice gap. T1-weighted structural images were also acquired, co-registered with the mean EPI, normalised to a standard T1 template, and averaged across subjects to allow group level anatomical localization. An atlas of the basal ganglia (INSERM,
Hôpital de la Salpêtrière, Paris, France) was also deformed on average structural images to further ensure anatomical localisation. EPI images were analysed in an event-related manner, within a general linear model, using the statistical parametric mapping software SPM5 (Wellcome Department of Imaging Neuroscience, London, UK). The first 5 volumes of each session were discarded, to allow for T1 equilibration effects. Pre-processing consisted of spatial realignment, normalisation using the same transformation as structural images, and spatial smoothing using a Gaussian kernel with a full-width at half-maximum of 6mm.

We used a single statistical linear regression model for all our analyses, as follows. Each trial was modelled as having only 1 time point, corresponding to stimulus onset. Separate regressors were created for the 6 stimuli conditions (2 stimuli * 3 durations). For each condition the force produced by the subject was also included as parametric modulation. Thus the design matrix contained 12 regressors of interest, all convolved with a canonical haemodynamic response function (HRF). To correct for motion artefact, subject-specific realignment parameters were modelled as covariates of no interest. Linear contrasts of regression coefficients were computed at the individual subject level and then taken to a group level random effects analysis (one-sample t-test). A threshold of $P < 0.05$ after family-wise error (FWE) correction for multiple comparisons was applied to avoid any a priori on brain localisation. A more liberal threshold ($P < 0.001$, uncorrected) was also used to observe the extension of significant activations.

Our original question was whether brain circuits underlying subliminal and conscious motivation can be dissociated. We calculated a two-way analysis of variance, the two factors being motivation (amount of money at stake) and reportability (duration of stimulus display). We found no significant main effect of reportability, but significant main effect of motivation, as well as significant interaction between motivation and reportability, in the basal forebrain only (see Fig. S3). Moreover, positive effect of motivation (£1-1p) was activation of the same basal forebrain region, but with increased amplitude and significance, from short to long display durations. These data suggest that the brain circuits underlying subliminal motivation are not different from those underlying conscious motivation. We then explicitly addressed the question of whether the brain region responsible for conscious motivation also works at subliminal level. This region of interest (shown in Fig. 2) was defined as the set of voxels significantly activated, after FWE correction over the entire brain, by the contrast between pounds and pennies in the conscious condition (£1-1p, 100 ms). Within each subject, parameter estimates were averaged over these voxels, separately for all modalities of motivation and reportability. Significance of activation, for each of the 3 stimulus durations, was assessed at group level with paired t-tests between monetary incentives (£1-1p).
Corresponding time courses (Fig. 3) were estimated by fitting a flexible basis set of finite impulse responses (FIRs), separated from the next by one scan (1.95s). Finally, brain areas underlying force production were isolated in a contrast including all parametric regressors whatever the condition (see Fig. 2).
INSTRUCTIONS

Part one is designed to determine at which threshold you can see masked coins.
Part two is designed to measure your maximal force.
Part three will allow you to use your force to win some of the coins.
Part four is designed to check out that you actually see the coins when you say so.

Part one
The masked coins that will be displayed on the screen can be either 1p (one penny) or £1 (one pound).
Whatever it is, you will be asked to say whether you have seen it or not.
Use your index finger for a “seen” response and the middle finger for an “unseen” response.
Only choose “seen” when you are sure to have distinctly perceived all or part of the coin.
We will start with long durations and go to shorter ones until you consistently say that you see nothing.

Part two
The different steps will be announced on the screen.
During baseline calibration just do nothing.
During maximal force measurement squeeze the power grip as hard as you can.
During practice see how high you can move up the fluid in the thermometer displayed on the screen.

Part three
Every time a masked coin is displayed on the screen you will have to squeeze the power grip.
Squeezing the grip makes the fluid level move up in the thermometer as before.
The height you reach determines the fraction of the coin you will be allowed to keep.
The total amount of money that you have won so far will be written on the screen after every trial.
In short: the more you squeeze the more money you win!

Part four
Now you will have to say which coin was displayed on the screen.
Just have a guess when you have not seen anything.
Four choices will be available: seen £1 / seen 1p / guess £1 / guess 1p.
The 4 responses respectively correspond to your 4 fingers put of the keypad, from left to right.
Again choose the “seen” options when you are sure to have distinctly perceived all or part of the coin.
**Fig. S1 Evolution of autonomic and behavioral responses with successive trials.** Response peaks were extracted for each trial and expressed as percentages of the highest measure. The 3 sessions were concatenated to show all 45 trials for different stimuli (black is £1 and white is 1p) and durations (growing thicknesses are 17, 50 and 100 ms).
**Fig. S2 Correlation between motivational effects and perceptive awareness.** Y-axis indicates the difference between pounds and pennies on hand grip force (top) and activation of ventral pallidum (bottom). X-axis represents perception of monetary incentives according to two criterions: subjective feeling of seeing (left) and proportion of correct guessing (right). Each point is one subject tested with one duration of stimuli display. Red points are considered subliminal from being within the 95% confidence interval of perception assessed at the shortest duration (17 ms). According to criterion 1, subliminal perception means that percentage of seen responses is not different from 0. According to criterion 2, subliminal perception means that percentage of correct responses is not different from chance level (0.5).
Fig. S3 Statistical parametric maps from 2-by-3 analysis of variance. The 2 factors were amount of money (motivation) and duration of display (reportability). To show the extent of activations a liberal threshold ($P < 0.001$, uncorrected) has been used, resulting in some obvious false positives. The $[x \ y \ z]$ coordinates of the different maxima refer to the MNI space. Axial and coronal slices were taken at global maxima of interest indicated by red arrows on the glass brains.